

**WHAT IS CLAIMED IS:**

1. A proton electrolyte membrane fuel cell electrode, comprising:
  - (a) a plurality of carbon nanotubes, wherein the plurality forms a mat of carbon  
 5 nanotubes, wherein the mat has a planar area and wherein the mat has a  
 thickness greater than one micron, and
  - (b) a catalyst metal selected from the group consisting of chromium (Cr),  
 molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc),  
 rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co),  
 10 rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt),  
 copper (Cu), silver (Ag), gold (Au), zinc (Zn), tin (Sn), aluminum (Al), and  
 combinations thereof, in contact with the mat of carbon nanotubes.
2. The electrode of claim 1 wherein the carbon nanotubes are selected from the  
 group consisting of single-wall carbon nanotubes, multi-wall carbon nanotubes  
 15 and a combination thereof.
3. The electrode of claim 1 wherein the carbon nanotubes are derivatized with a  
 functional group.
4. The electrode of claim 3 wherein the functional group is a carboxylic acid group.
5. The electrode of claim 1 wherein the catalyst metal comprises platinum.
- 20 6. The electrode of claim 1 wherein the catalyst metal comprises platinum and  
 ruthenium.
7. The electrode of claim 1 wherein the catalyst metal is present in an amount less  
 than  $400 \mu\text{g}/\text{cm}^2$  of the planar area of the mat of the carbon nanotubes.
8. The electrode of claim 1 wherein the catalyst metal is present in an amount less  
 25 than  $100 \mu\text{g}/\text{cm}^2$  of the planar area of the mat of the carbon nanotubes.
9. The electrode of claim 1 wherein the catalyst metal is present in an amount less  
 than  $50 \mu\text{g}/\text{cm}^2$  of the planar area of the mat of the carbon nanotubes.

10. The electrode of claim 1 wherein the catalyst metal is present in an amount less than  $25 \mu\text{g}/\text{cm}^2$  of the planar area of the mat of the carbon nanotubes.
11. The electrode of claim 1 wherein the catalyst metal is present in an amount less than  $10 \mu\text{g}/\text{cm}^2$  of the planar area of the mat of the carbon nanotubes.
- 5 12. The electrode of claim 1 wherein the electrode is a component in a hydrogen/oxygen proton exchange membrane fuel cell (PEMFC).
13. The electrode of claim 1 wherein a) the electrode is a component in a hydrogen/oxygen PEMFC, wherein b) the catalyst metal comprises platinum, wherein c) the carbon nanotubes are single-wall carbon nanotubes, and wherein d)  
10 the electrode provides greater than  $1 \text{ mA}/\text{cm}^2$  per  $\mu\text{g Pt}/\text{cm}^2$  of the planar area of the mat of carbon nanotubes.
14. The electrode of claim 13 wherein the electrode provides greater than  $10 \text{ mA}/\text{cm}^2$  per  $\mu\text{g Pt}/\text{cm}^2$  of the planar area of the mat of carbon nanotubes.
15. The electrode of claim 13 wherein the electrode provides greater than  $50 \text{ mA}/\text{cm}^2$  per  $\mu\text{g Pt}/\text{cm}^2$  of the planar area of the mat of carbon nanotubes.  
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16. The electrode of claim 13 wherein the electrode provides greater than  $100 \text{ mA}/\text{cm}^2$  per  $\mu\text{g Pt}/\text{cm}^2$  of the planar area of the mat of carbon nanotubes.
17. The electrode of claim 1 wherein the electrode is a component in a direct methanol fuel cell (DMFC).
- 20 18. A method for preparing a fuel cell membrane electrode, comprising
  - (a) associating a catalytic metal selected from the group consisting of a catalyst metal selected from the group consisting of chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir),  
25 nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), zinc (Zn), tin (Sn), aluminum (Al), and combinations thereof, with a

plurality of carbon nanotubes to form a plurality of carbon nanotubes with associated catalytic metal, and

(b) forming a membrane electrode comprising a plurality of carbon nanotubes with associated catalytic metal.

- 5 19. The method of claim 18 wherein the carbon nanotubes are selected from the group consisting of single-wall carbon nanotubes, multi-wall carbon nanotubes and a combination thereof
20. The method of claim 18 wherein the plurality of carbon nanotubes are derivatized with a functional group.
- 10 21. The method of claim 20 wherein the functional group is a carboxylic acid group.
22. The method of claim 18 wherein associating is done by a method selected from the group consisting of chemical vapor deposition, electrochemical deposition, physical vapor deposition, thermal deposition, cathodic arc deposition, ion sputtering, evaporative sputtering, molecular beam epitaxy, ion beam assisted deposition, jet vapor deposition, and combinations thereof.
- 15 23. The method of claim 18 wherein the associating is done by a method selected from the group consisting of chemical deposition, electrochemical deposition, evaporative sputtering, molecular beam epitaxy, and combinations thereof.
24. The method of claim 18 wherein the catalytic metal comprises platinum.
- 20 25. The method of claim 18 wherein the catalytic metal comprises platinum and ruthenium.
26. The method of claim 18 wherein the associating is done by chemical deposition of a catalyst metal precursor.
27. The method of claim 26 wherein the catalyst metal precursor comprises chloroplatinic acid.
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28. The method of claim 26 wherein the catalyst metal precursor is converted to a catalytically active metal by subjecting the catalyst metal precursor to metal reduction.
29. The method of claim 28 wherein metal reduction is done by a method selected from the group consisting of hydrogen reduction, chemical reduction, and a combination thereof.
30. The method of claim 29 wherein the metal reduction is done by hydrogen reduction.
31. The method of claim 28 wherein the catalytically active metal is in the form of metal particles on the carbon nanotubes.
32. The method of claim 18 wherein the forming is done on a proton exchange membrane by a method selected from the group consisting of painting, spraying, subliming, electrolytic deposition, centrifugation, filtering a suspension using the element, and combinations thereof.
33. The method of claim 18 wherein the forming is done on a gas diffusion layer by a method selected from the group consisting of painting, spraying, subliming, electrolytic deposition, centrifugation, filtering a suspension using the element, and combinations thereof.
34. The method of claim 18 further comprising mixing an ionomeric resin with the plurality of carbon nanotubes with associated catalytic metal.
35. The method of claim 34 wherein the ionomeric resin comprises a perfluorosulfonic acid/PTFE copolymer.
36. A membrane electrode assembly, comprising a proton exchange membrane, an anode electrode, a cathode electrode and carbon nanotubes, wherein the carbon nanotubes are positioned between the anode electrode and the proton exchange membrane.

37. The membrane electrode assembly of claim 36 wherein the carbon nanotubes are selected from the group consisting of single-wall carbon nanotubes, multi-wall carbon nanotubes and a combination thereof.
38. The membrane electrode assembly of claim 36 wherein the carbon nanotubes are coated with perfluorosulfonic acid/PTFE copolymer.
39. The membrane electrode assembly of claim 36 wherein the membrane electrode assembly is in a hydrogen/oxygen PEM fuel cell.
40. The membrane electrode assembly of claim 36 wherein the membrane electrode assembly is in a direct methanol fuel cell.
41. A method for preparing an membrane electrode assembly, comprising:
- (a) preparing an ink comprising carbon nanotubes and catalytic metal; and
  - (b) coating the ink on one or more sides of a proton exchange membrane.
42. The method of claim 41 wherein the carbon nanotubes are selected from the group consisting of single-wall carbon nanotubes, multi-wall carbon nanotubes and a combination thereof.
43. The method of claim 41 wherein the ink further comprises a perfluorosulfonic acid/PTFE copolymer.
44. The method of claim 41 wherein the catalytic metal is selected from the group consisting of chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), zinc (Zn), tin (Sn), aluminum (Al), and combinations thereof.
45. The method of claim 41 wherein the catalytic metal comprises platinum.

46. The method of claim 41 wherein the catalytic metal comprises platinum and ruthenium.
47. A catalyst ink comprising carbon nanotubes and catalytic metal selected from the group consisting of consisting of chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), zinc (Zn), tin (Sn), aluminum (Al), and combinations thereof.
48. The catalyst ink of claim 47 wherein the catalytic metal comprises platinum.
49. The catalyst ink of claim 47 wherein the catalytic metal comprises platinum and ruthenium.
50. The catalyst ink of claim 47 wherein the carbon nanotubes are selected from the group consisting of single-wall carbon nanotubes, multi-wall carbon nanotubes and a combination thereof.
51. The catalyst ink of claim 47 further comprising an ionomeric resin.
52. The catalyst ink of claim 51 wherein the ionomeric resin comprises a perfluorosulfonic acid/PTFE copolymer.
53. The catalyst ink of claim 47 wherein the ink is in contact with a proton exchange membrane.
54. The catalyst ink of claim 47 wherein the ink is a component of a fuel cell.
55. The catalyst ink of claim 54 wherein the fuel cell is a PEM fuel cell.
56. The catalyst ink of claim 54 wherein the fuel cell is a DMFC.
57. A PEM fuel cell comprising an anode electrode, a cathode electrode and a proton exchange membrane, wherein the anode electrode comprises single-wall carbon

nanotubes and wherein the single-wall carbon nanotubes support platinum-containing metal particles.

58. The fuel cell of claim 57 wherein the cathode electrode comprises single-wall carbon nanotubes wherein the single-wall carbon nanotubes support platinum-containing metal particles.
59. The fuel cell of claim 57 wherein the single-wall carbon nanotubes in the anode electrode are derivatized with a functional group.
60. The fuel cell of claim 57 wherein the single-wall carbon nanotubes in the cathode electrode are derivatized with a functional group.
61. The fuel cell of claim 57 wherein the fuel cell is a single stack fuel cell.
62. The fuel cell of claim 57 wherein the fuel cell is a multi-stack fuel cell.